INFO

COMMONWEALTH OF AUSTRALIA

BUREAU OF METEOROLOGY

PROJECT REPORT 57/1640

MARCH 1959

DETERMINATION OF COMFORT ZONES FOR AUSTRALIA

BY

CONSTANCE M. VENVILLE

A series of publications, "Project Reports", has been introduced to ensure prompt circulation of project reports undertaken within the Bureau.

These reports will be distributed within the Bureau of Meteorology and to other interested organisations. Each "external" distribution will depend on the content of the particular project report. Reference to this project report should be made in the following manner:

"Bureau of Meteorology Project Report 57/1640 of March 1959".

DETERMINATION OF COMFORT ZONES FOR AUSTRALIA

ABSTRACT: Using recent developments of D.H.K. Lee, a map was constructed showing bodily discomfort due to heat and its variations across Australia during morning and afternoon. There is relatively comfortable zone including all the settled areas of southern Australia and extending, in the east, to the coastal districts of southern Queensland and in the west, to the Geraldton area of Western Australia. Beyond this zone there is generally speaking an increase in discomfort northwards with conditions somewhat ameliorated by altitude in areas such as the Atherton Tablelands. No Australian station was found to be uncomfortably hot in July but some in the north approached this limit in the afternoon. It was found that bodily strain due to cold was only serious over a smallalpine area and in parts of elevated Tasmania and was restricted to the winter months. Data for New Guinea were not amenable to the same statistical treatment in view of the lack of seasonal variation and analogous zones of discomfort were deduced with the help of the correlation between thermal strain and height; these reduced to:

(1) an uncomfortable "sea level zone" (up to 1000 ft)

(2) a zone above about 2500' which was on the whole relatively comfortable

(3) the intermediate sub-elevated zone which experienced diurnal variations in degrees of comfort.

1. INTRODUCTION

For many years the basis of comfort used by the Public Service Board in determining District Allowances in Australia was the effective temperature for January 9a.m. The effective temperature concept was developed by the American Society of Heating and Ventilating Engineers from a series of carefully controlled experiments to determine the response of individuals to varying wind speeds and dry and wet bulb temperatures. Effective temperature may be defined as"the temperature of a still, saturated atmosphere which would have the same general effect upon comfort as the atmosphere in question" (Lee, 1947). Nomograms drawn up by workers of the A.S.H.V.E. for determining effective temperature proved useful in practice and for many years effective temperature was the best index of comfort available.

Lee (1947) states his approach as follows: "It would appear that a satisfactory measure of the thermal relationship between the environment and the human body will be possible only when we can compare quantitatively the rate at which the environment can accept heat from the body on the one hand, with the rate at which it is being produced by the body on the other. Once the necessary thermodynamic equations are established, it should be a fairly simple matter to establish the optimum or neutral point, and to demarcate zone of increasing strain or either side of that point". He drew up stress-strain diagrams and formulated a tentative equation (for heat strain) defining the unmeasurable resultant strain in terms of the measurable applied stress (Lee 1956). An equation for cold strain has now been added (Lee 1958).

2. REVIEW OF METHOD

(i) Thermal Strain

When Lee plotted on a psychrometric chart the combinations of temperature and humidity reported from actual experiments to produce the same bodily response in various individuals he obtained a series of straight lines each representing conditions of equal strain. He then sought to express the strain, or cost to the individual of interference with a balanced bodily state with respect to heat, in terms of applied stress which exists when there is any interference with this balanced state, an equation for which had been worked out by Burton.

$$F = (M-W) - \frac{5.55\ (34-t)}{I_a + I_c} - .00033\ V\ (46 - p) \quad (1)$$

M = metabolic rate)
W = rate of energy expenditure as external work) in k. cal/sq.m/hr.

t = air temperature in ^{o}C

p = vapour pressure in of mercury

I_a = resistance of air and I_c of clothing to the outward passage of heat in clo units*

V = volume of respired air in litres/hour

* = The clo unit was devised by Gagge, Burton and Bazett. One clo is the amount of insulation necessary to maintain in comfort a sitting-resting person in a normally ventilated room (air movement 20 feet/minute) at a temperature of $70^{o}F$ and humidity of the air less than 50%.

The equation to each straight line of equal strain on Lee's diagram may be written:

$$\frac{a}{G}t + p = C \quad \text{where G = strain; a, c are constant or}$$

$$G = \frac{at}{c-p} \quad (2)$$

The expression for stress (1) was substituted for t in (2) since it is largely a linear function of air temperature. The equation was then modified to provide for the effect of air movement (r_a) and clothing (r_c) on resistance to the outward passage of water vapour.

The tentative equation for thermal strain now reads:-

$$G = a \frac{(M-W) - \frac{5.55(34 - t)}{I_a + I_c} - .00033\ V(46-p)}{\frac{c - p}{r_a + r_c}}^{d}$$

where d is a constant determined from experimental observations and r_a and r_c are respectively the resistance of air and of clothing to outward passage of water vapour in mm of still air equivalent.

It is capable of including all factors affecting the heat balance of the body and further work is being done by Lee on the effect of solar radiation and its inclusion in this type of equation.

A nomogram shown in Fig 1 was drawn up by Lee (1956), for calculation of strain at varying temperatures and vapour pressures for an acclimatised man doing moderate work in an environment with moderate air movement and wearing normal clothing. This was used in the calculations of thermal strain on which the accompanying maps are based, together with the tentative index given in Table 1 (Lee 1956). For other levels of clothing, air movement and activity adjusting grids would be necessary.

Table 1 Tentative Thermal Strain Index

Most comfortable below	$4\frac{1}{2}$
None comfortable above	$6 - 8\frac{1}{2}$
Recommended upper limit for day's work (winter)	10
Recommended upper limit for day's work (summer)	20
Mental performance of average man commences to deteriorate	22
Distress in 2 hours) Collapse in 5 hours)	30
Distress in 1 hour) Collapse in 3 hours)	45
Collapse in 1 hour	75
Collapse in 40 min.	100
Collapse in 30 min.	200

(ii) Cold Strain

A separate equation is necessary for cold strain since, as Lee points out (1958), the physiological reactions of the human body to cold are not just the obverse of its reactions to heat. Vapour pressure plays very little part in reaction to cold, insulation a comparatively small part in reaction to heat.

As in the formula for thermal strain, it does not yet include a term involving radiant exchange with the surroundings.

$$G = 1.11 \frac{5.55(34-t)}{I_a + I_c} + M\,(.153 + .0015(34-t)) - (M-W)$$

G values range from 0 at a point of thermal equilibrium to 200 when the body temperature is dropping at a rate of 5°C/hour.

3. APPLICATION OF THERMAL STRAIN FORMULA

(i) Australia

Values of thermal strain were calculated for all available stations from average dry and wet bulb temperatures over as long a period as possible for January 9a.m. and 3p.m. and July 9a.m. and 3p.m. July is the coldest month of the year throughout Australia and January the month of highest dry bulb temperatures over the greatest part excepting the extreme north and the extreme south. However, the wet bulb temperature

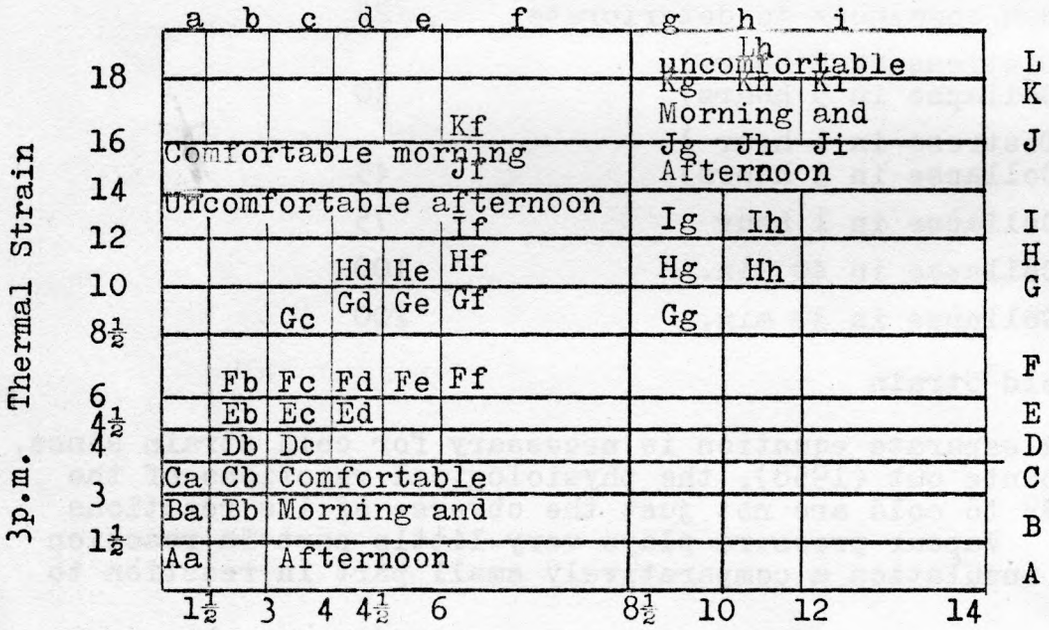
largely determines the value of thermal strain and the difference between the thermal strain value for January and for the month of highest dry bulb temperature is slight.

Maps were plotted for January 9a.m. (Fig 2), 3p.m. (Fig 3), July 9a.m., 3p.m. and isopleths drawn at intervals indicated by Lee's tentative index of significant thermal strain values (Table 1) i.e. at $1\frac{1}{2}$, 3, 4, $4\frac{1}{2}$, 6, $8\frac{1}{2}$, 10 (and thereafter at intervals of 2 units).

It is considered that the climate of the southeastern area of Australia is tolerable to the normal worker. Several towns considered to be on the borderline of climatic comfort when plotted on the January 3p.m. map (Fig 3) were found to lie mostly between the 6 and $8\frac{1}{2}$ isopleths. According to the index some people are still comfortable at thermal strain values 6 to $8\frac{1}{2}$, so it was assumed that the $8\frac{1}{2}$ line on the January 3p.m. map would form the "comfort boundary".

The maps for January 9a.m. and 3p.m. were superimposed giving areas which were labelled alphabetically as indicated in Fig 4.

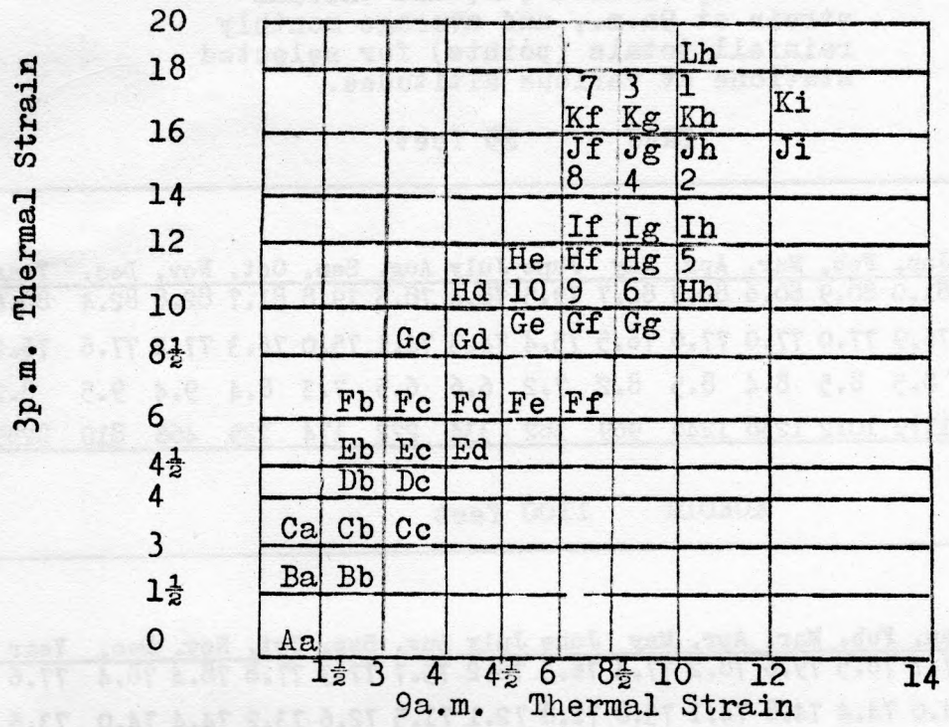
Table 2 Key for interpretation of Fig 4



Since the number of zones requested by the Public Service Board was about 12, some combination of the areas was necessary. Firm boundaries were retained at the 3p.m. "comfort boundary" of $8\frac{1}{2}$ and for 9a.m. values of $4\frac{1}{2}$, 6, $8\frac{1}{2}$ and 10. Where it was necessary to separate 2 areas, one of higher discomfort in the morning, the other in the afternoon, a higher rating was given to the area of greater discomfort in the morning since over the whole day conditions would be more uncomfortable e.g. Zone 6 Hg Gg
" 7 Kf

The "10" isopleth was not retained throughout in the afternoon values since on inspection it was found that the areas Gd, Ge, Gf, Gg were very small and may be regarded as transition zones and they were therefore combined as shown in Fig 5.

Table 3 Key for interpretation of Fig 5



No Australian station is uncomfortably hot at 9a.m. in July.

At 3p.m. some northern areas have thermal strain values 6 to 8½. The "6" line for July 3p.m. is included in Fig 5, since places to the north of this line tend to be uncomfortable throughout the year.

(ii) New Guinea

Here January and July have no significance as hottest and coldest months, and temperatures vary little throughout the year.

For all available stations thermal strain was calculated from yearly average dry and wet bulb temperatures at 9a.m. and 3p.m. These values were plotted against height above mean sea level. From the limited information available it appears that above 2500 feet a person would not feel discomfort due to heat (T.S. 6). Between about 1000 feet and 2500 feet stations would be "comfortable" in the mornings but tending to be uncomfortable in the afternoons since the values of thermal strain, although only 6 to 8½, apply throughout the year. For stations below 1000 feet some would be relatively comfortable in the mornings (T.S. 6 to 8½), others always uncomfortable. In Fig 6 boundary is shown between these two areas but this is very approximate in view of the limited amount of information available.

For selected stations at various altitudes monthly distribution of dry and wet bulb temperatures, thermal strain (and rainfall) are shown in Table 4.

Table 4 Average monthly mean dry bulb and wet bulb temperatures (°F) and thermal strain at 9a.m., and average monthly rainfall totals (points) for selected stations at various altitudes.

DARU 25 feet

Element	Years of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
9a.m.DB	16	81.0	80.9	80.6	80.9	80.7	79.5	78.4	78.5	79.8	81.7	82.8	82.4	80.6
9a.m.WB	16	76.9	77.0	77.0	77.0	76.5	75.4	74.3	74.1	75.0	76.3	77.2	77.6	76.2
9a.m.TS	16	8.5	8.5	8.4	8.5	8.2	7.2	6.6	6.5	7.3	8.4	9.4	9.5	8.2
Rainfall	31	1179	1012	1238	1248	969	382	334	222	174	225	466	810	8259

KOKODA 1100 feet

Element	Years of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
9a.m.DB	8	77.7	78.5	79.6	78.2	77.3	76.3	76.2	75.7	77.3	77.8	78.4	78.4	77.6
9a.m.WB	8	74.0	74.4	74.8	74.1	73.8	72.8	72.1	71.5	72.6	73.2	74.4	74.0	73.5
9a.m.TS	8	6.2	6.8	7.1	6.5	6.0	5.6	5.1	4.9	5.7	6.0	6.6	6.5	6.0
Rainfall	10	1295	1205	1602	1364	1293	761	653	950	1056	1131	1441	1499	14250

LAKE KUTUBU 2650 feet

Element	Years of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
9a.m.DB	2 to 3	71.6	71.4	71.1	71.8	71.9	71.0	71.1	70.8	71.2	72.7	72.5	71.6	72.0
9a.m.WB	2 to 3	68.1	68.3	67.9	69.1	69.0	68.3	67.5	68.3	68.5	69.2	68.8	68.1	68.5
3p.m.DB	2 to 3	78.0	78.7	79.4	78.0	79.6	78.7	77.3	76.6	77.5	78.2	78.5	77.5	78.2
3p.m.WB	2 to 3	71.1	73.9	71.1	73.5	72.7	72.1	70.9	71.5	71.8	71.3	71.1	70.6	71.8
9a.m.TS	2 to 3	3.0	3.1	3.0	3.4	3.4	3.1	3.0	3.1	3.1	3.6	3.5	3.1	3.3
3p.m.TS		5.5	6.5	5.9	6.1	6.4	6.0	5.1	5.0	5.5	5.6	5.5	5.1	5.7
Rainfall	4 to 5	1303	1577	1176	1906	1623	1172	1485	1484	1986	1816	1413	1556	18502

LUMI 1750 feet

Element	Years of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
9a.m.DB	2	73.9	73.3	72.6	73.4	73.5	72.3	71.9	72.8	73.3	73.3	73.7	74.0	73.2
9a.m.WB	2	71.2	71.2	70.6	71.2	71.5	70.3	69.6	70.0	70.6	70.7	71.0	71.3	70.8
3p.m.DB	2	79.2	78.7	78.9	77.5	78.3	78.2	79.2	80.5	79.8	78.8	77.9	78.9	78.8
3p.m.WB	2	73.8	73.8	74.0	73.5	73.8	72.9	72.2	72.2	72.3	73.1	72.9	73.7	73.2
9a.m.TS		4.3	4.1	3.9	4.1	4.3	3.8	3.5	3.8	4.0	4.0	4.1	4.4	4.0
3p.m.TS		6.5	6.4	6.6	6.0	6.3	6.0	6.1	6.6	6.5	6.1	6.0	6.4	6.3
Rainfall	5 to 6	1219	997	967	1384	516	344	354	621	720	862	1281	985	10250

MADANG 20 feet

Element	Years of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
9a.m.DB	14	80.7	80.2	80.8	80.6	81.1	81.2	80.8	81.0	81.9	82.1	81.8	81.2	81.1
9a.m.WB	14	77.2	76.9	77.4	77.5	77.8	77.6	77.3	77.0	77.7	77.8	77.8	77.6	77.5
3p.m.DB	13	84.8	84.7	85.0	85.2	85.8	85.7	85.4	84.9	85.2	85.4	85.4	85.3	85.2
3p.m.WB	13	79.4	79.6	79.5	79.6	79.7	79.5	79.0	78.5	78.8	79.1	79.3	79.6	79.3
9a.m.TS		8.5	8.3	8.6	8.6	9.0	8.9	8.5	8.5	9.4	9.5	9.5	8.9	9.3
3p.m.TS		11.3	11.3	11.3	11.5	12.0	11.6	11.2	10.9	11.1	11.3	11.4	11.6	11.4
Rainfall	21	1248	1162	1501	1715	1481	1070	786	480	584	1021	1330	1435	13813

MT. HAGEN 5350 feet

Element	Years of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
9a.m.DB	3 to 5	64.7	64.9	64.4	64.7	64.4	62.8	62.0	62.0	64.1	65.3	66.1	65.9	64.3
9a.m.WB	3 to 5	61.6	61.5	61.4	61.7	61.2	60.2	59.6	59.6	60.5	61.0	61.8	61.4	61.0
3p.m.DB	3 to 5	71.1	70.9	71.3	72.4	71.9	72.3	71.3	70.9	71.2	71.8	70.5	69.9	71.7
3p.m.WB	3 to 5	64.5	64.3	64.3	64.2	64.1	63.5	62.3	62.7	63.2	63.0	63.3	63.2	63.3
9a.m.TS		1.4	1.4	1.4	1.4	1.3	1.0	1.0	1.0	1.3	1.4	1.6	1.6	1.3
3p.m.TS		2.7	2.6	2.6	3.0	2.8	2.9	2.5	2.5	2.5	2.6	2.5	2.3	2.7
Rainfall	6	1147	1100	977	1156	589	474	424	693	913	709	963	918	10063

PORT MORESBY 126 feet

Element	Years of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
9a.m.DB	26	83.3	82.6	82.6	82.6	81.5	79.9	78.6	78.3	79.8	81.9	83.9	84.6	81.7
9a.m.WB	26	76.7	76.5	76.7	76.7	76.3	74.8	73.8	73.4	74.8	76.1	77.4	77.7	75.9
3p.m.DB	7	86.7	86.0	85.1	84.5	83.2	81.9	80.1	78.8	80.3	81.9	84.1	86.7	83.3
3p.m.WB	7	78.9	78.9	78.3	78.2	77.8	76.6	75.0	73.6	75.4	76.2	77.5	78.9	77.1
9a.m.TS		9.0	8.9	9.0	9.0	8.4	7.3	6.4	6.3	7.4	8.5	9.9	10.2	8.3
3p.m.TS		11.5	11.8	10.8	10.5	9.9	8.6	7.5	6.5	7.6	8.5	10.0	10.7	9.3
Rainfall	39	700	759	659	414	257	125	110	67	101	142	190	441	3965

In order to fit New Guinea into the scheme used for Australia the areas which are uncomfortable throughout the year were assigned to Zone 1 the worst area in January. Areas doubtful in the morning but uncomfortable in the afternoon were assigned to Zone 3 and those "comfortable" in the morning, doubtful in the afternoon to Zone 8.

Zones of Discomfort

The final eleven zones of discomfort due to heat comprise

Zone 1 to 9 - uncomfortable morning and afternoon in January in order of decreasing discomfort

Zones 10 and 11 - uncomfortable afternoon, comfortable morning in January

In Zone 12 conditions are comfortable throughout the day.

4. APPLICATION OF COLD STRAIN FORMULA

Values of cold strain were calculated from a nomogram designed by Lee (1958) where applicable, and where information was available in Australia for the coldest month July at 9a.m. and 3p.m. for a person normally clothed (I_a = clo) in an indoor environment (air movement slightly greater than 20 feet/minute and assuming that the indoor temperature is the same as the outdoor temperature).

Since so few 3p.m. temperature averages were available, only the 9a.m. values were considered. In Fig 5 (Zone 13) a boundary is shown at a value of 25 at 9a.m. in July. This gives an area which includes parts of the Alps and elevated areas of Tasmania. Inside this boundary there are not enough data available to allow any further subdivision.

The value of 25 was selected arbitrarily. The index for cold strain given by Lee is based on tolerance time i.e. the time, under the given conditions for the body to become dangerously cold, defined as the time at which the body has lost 80 k.cal of heat. No Australian stations for which average 9a.m. July temperature data are available exceed a cold strain value of 50 under the conditions mentioned above. However under exceptional weather conditions cold strain values would be considerably higher than those based on average conditions.

The significances given by Lee are:-

G value	5	10	25	50	100	200
Safe for	10 hrs	5 hrs	2 hrs	1 hrs	30 min	15 min

5. SUMMARY AND CONCLUSIONS

Australia

A recent development in the quantitative assessment of "comfort", the concept of thermal strain taking into account the effect of climatic elements temperature humidity and air movement, introduced by D.H.K. Lee, has been used as the basis for the construction of maps representing morning and afternoon conditions during the hottest and coldest months of the year. Areas of increasing discomfort were defined, taking as the comfort boundary a thermal strain value of $8\frac{1}{2}$ for January 3p.m. No Australian station was found to be uncomfortably hot in July but in the extreme north values exceed 6 at 3p.m. (Fig 7). Cold strain values for July were obtained where possible and the "25" isopleth was suggested as the limit above which cold strain was of significance.

New Guinea

Since there is no defined hottest or coldest month thermal strain values were obtained from yearly average dry and wet bulb temperatures. Zones were delineated by correlating thermal strain and altitude, and for coastal regions an attempt was made to subdivide the areas further on a basis of thermal strain values above or below $8\frac{1}{2}$ at 9a.m.

Lee, by considering the factors affecting the heat balance of the body has pointed the way to a precise single expression of factors affecting bodily comfort. Even with present omissions e.g. solar radiation and a quantitative measure of acclimatization, the concept is an improvement on previous standards, particularly in the indication of a neutral point.

Reference

Gagge, Burton and Bazett	1941	Science Vol. 94
Lee, D.H.K.	1947	Human Climatology and Tropical Settlement
	1956	Nomographic Assessment of Thermal Strain in Man
	1956	Proprioclimates of Man and Domestic Animals
	1958	Private communication (unpublished)

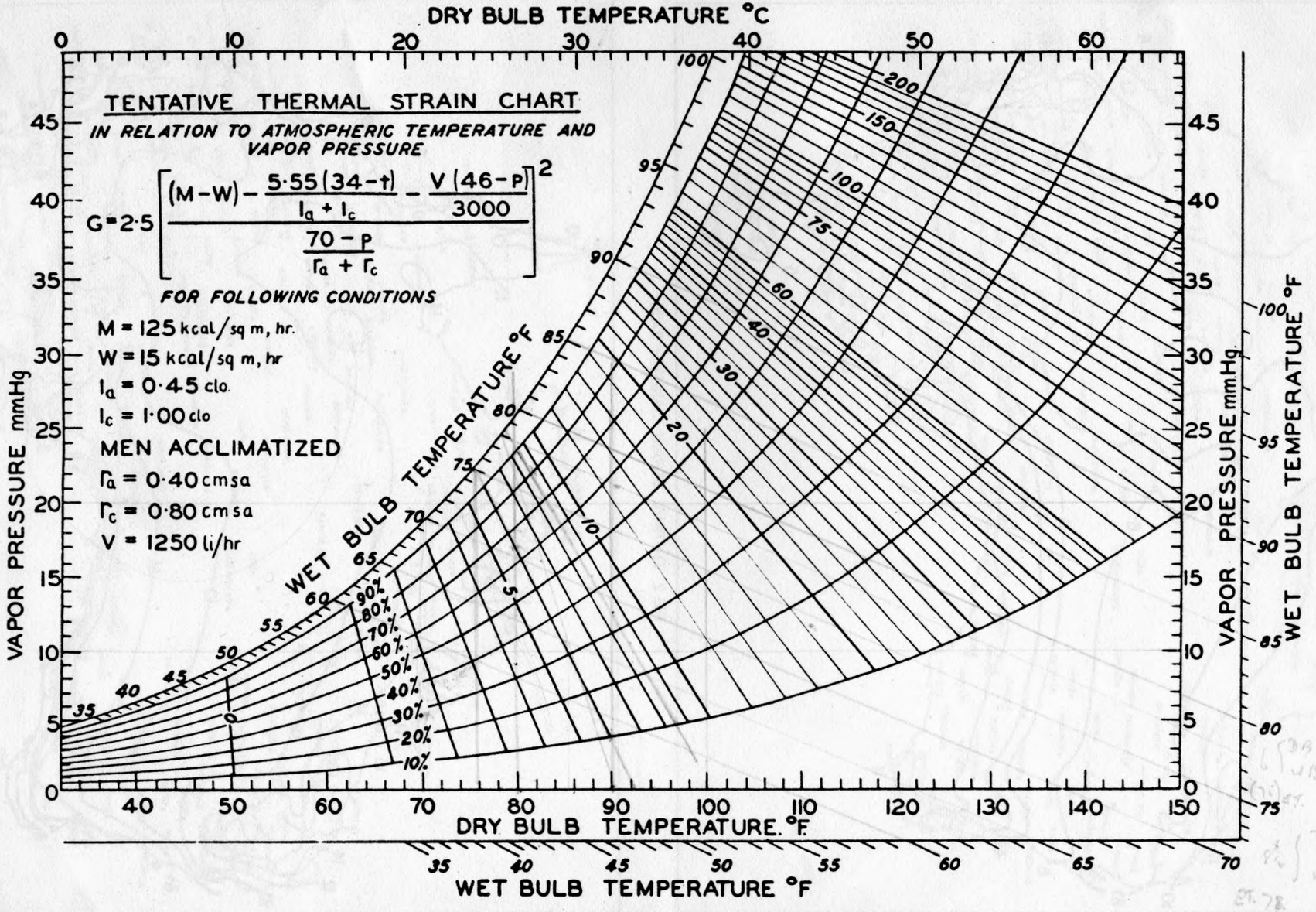

DRY BULB TEMPERATURE °C
TENTATIVE THERMAL STRAIN CHART
IN RELATION TO ATMOSPHERIC TEMPERATURE AND VAPOR PRESSURE
$G = 2{\cdot}5\left[\frac{(M-W)-\frac{5{\cdot}55(34-t)}{I_a+I_c}-\frac{V(46-P)}{3000}}{\frac{70-P}{r_a+r_c}}\right]^2$
FOR FOLLOWING CONDITIONS
M = 125 kcal/sq m, hr.
W = 15 kcal/sq m, hr
I_a = 0·45 clo.
I_c = 1·00 clo
MEN ACCLIMATIZED
r_a = 0·40 cmsa
r_c = 0·80 cmsa
V = 1250 li/hr
VAPOR PRESSURE mmHg
WET BULB TEMPERATURE °F
DRY BULB TEMPERATURE °F
WET BULB TEMPERATURE °F
VAPOR PRESSURE mmHg
WET BULB TEMPERATURE °F

FIG 1. TENTATIVE THERMAL STRAIN CHART

FIG 2. THERMAL STRAIN - JANUARY 9.A.M.

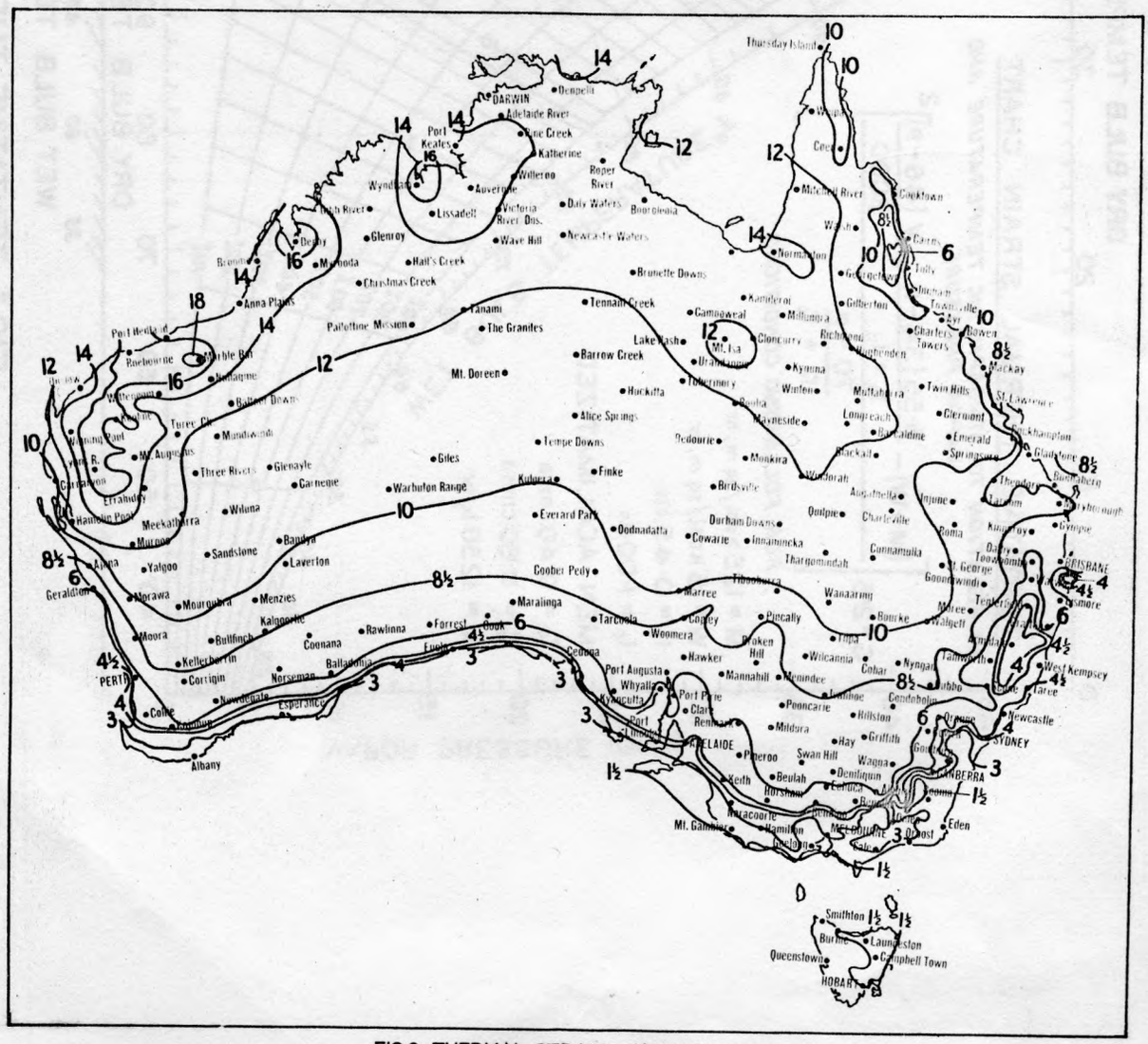


FIG 3. THERMAL STRAIN - JANUARY 3.P.M.

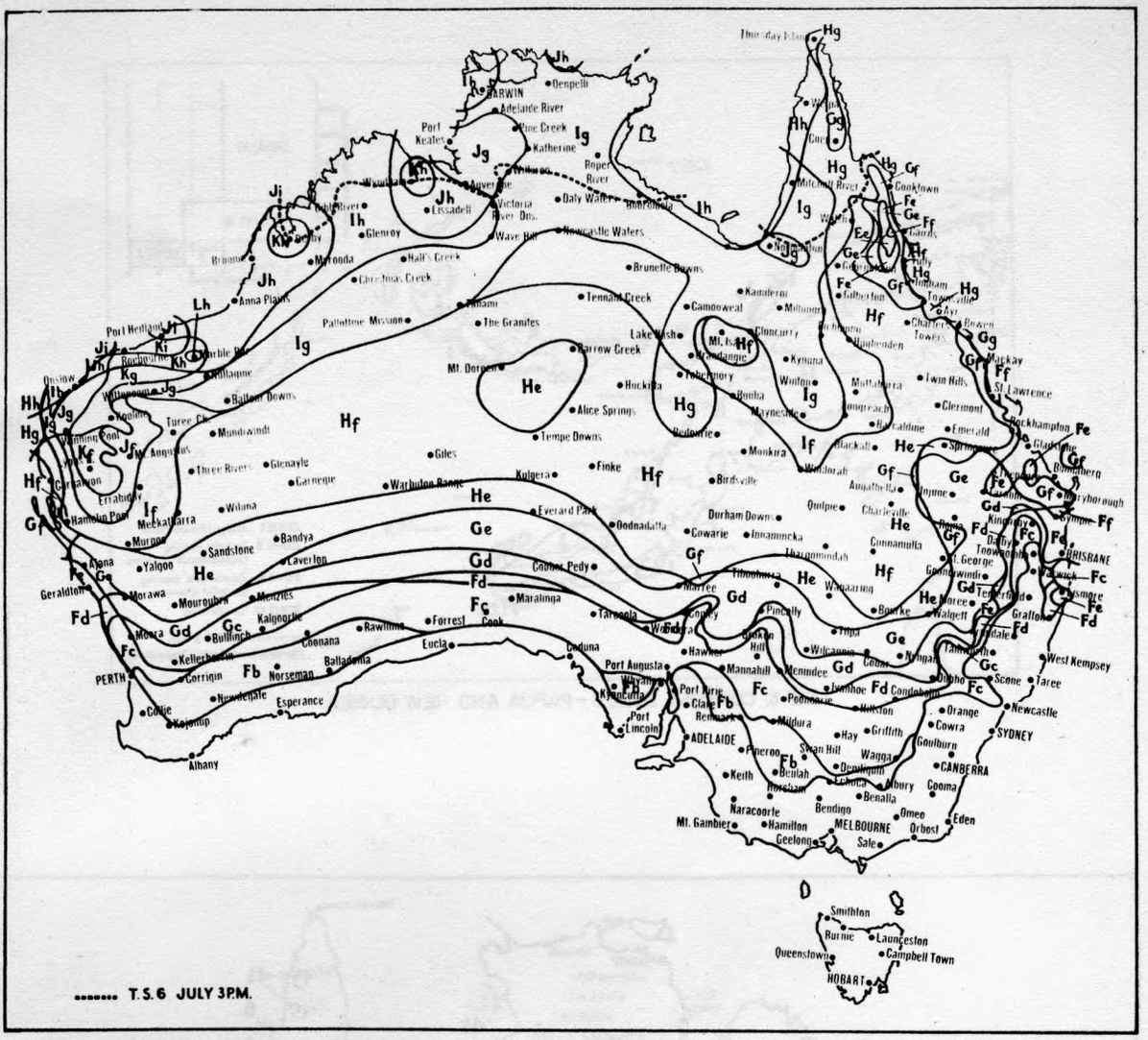


FIG 4. THERMAL STRAIN – JANUARY 9.A.M. AND JANUARY 3.P.M. (FOR AREAS EXCEEDING 6 T.S. JANUARY 3.P.M.)

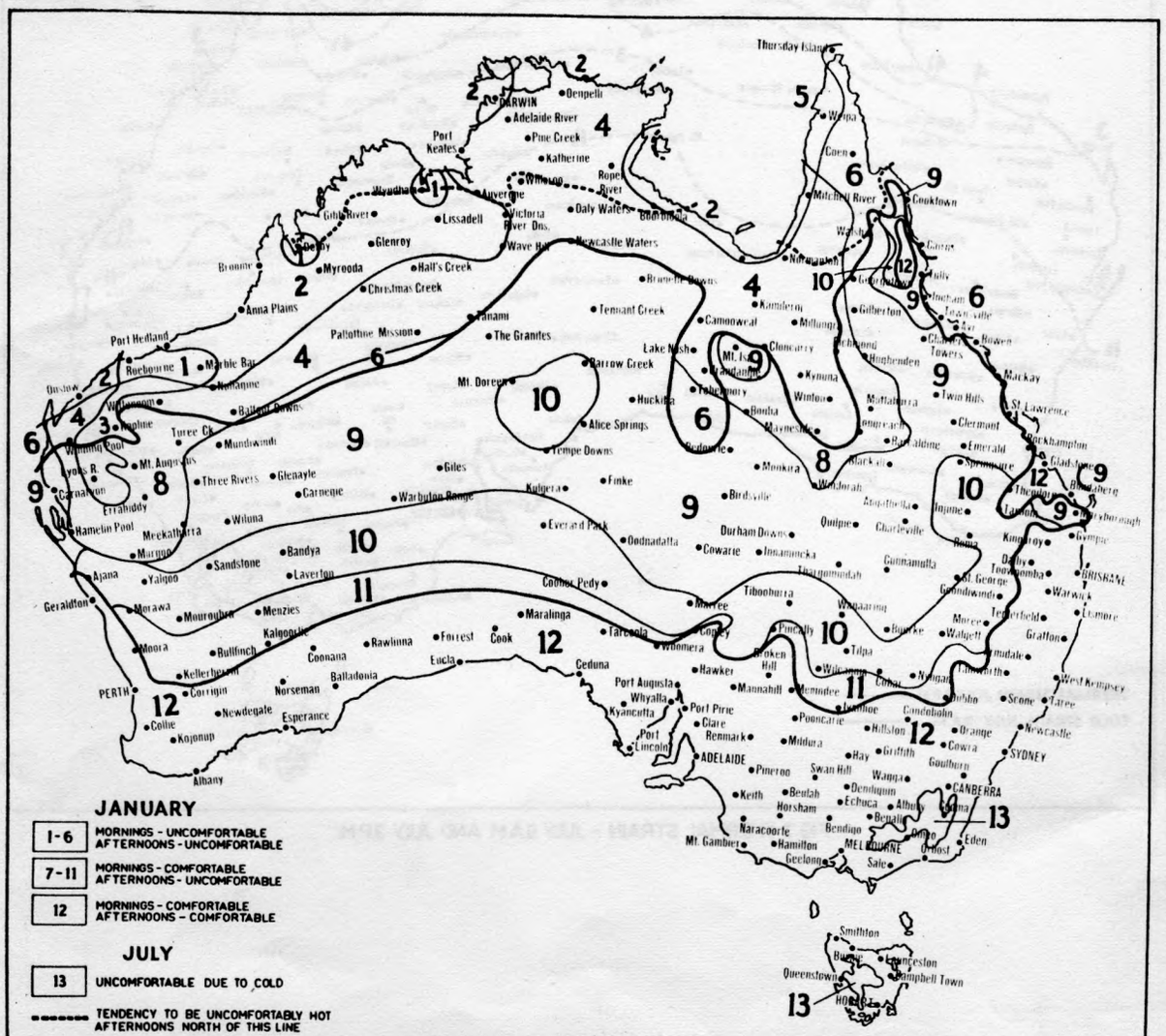


FIG 5. COMFORT ZONES - AUSTRALIA

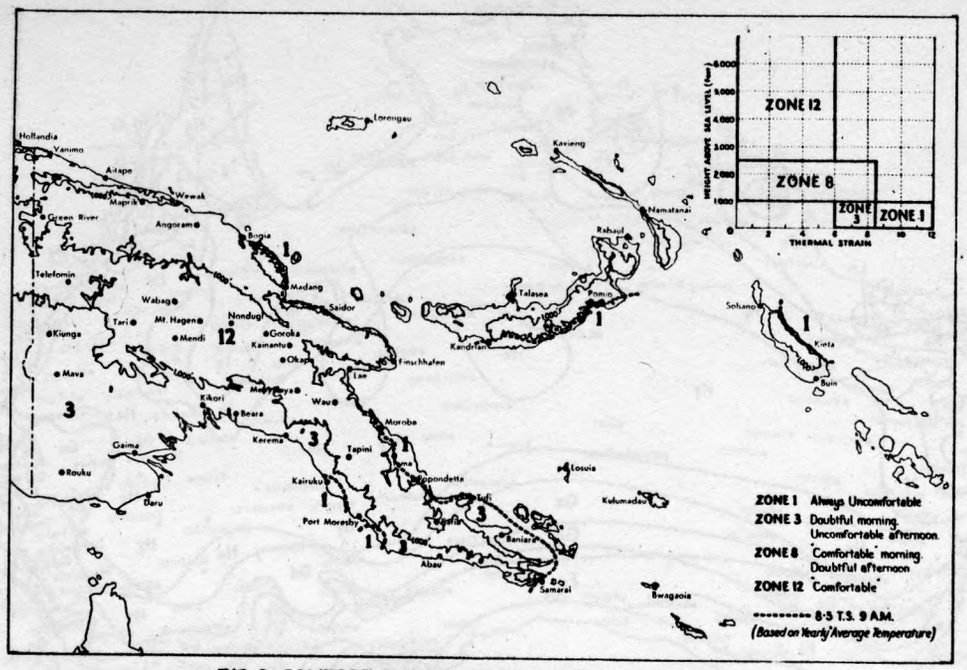


FIG 6. COMFORT ZONES - PAPUA AND NEW GUINEA

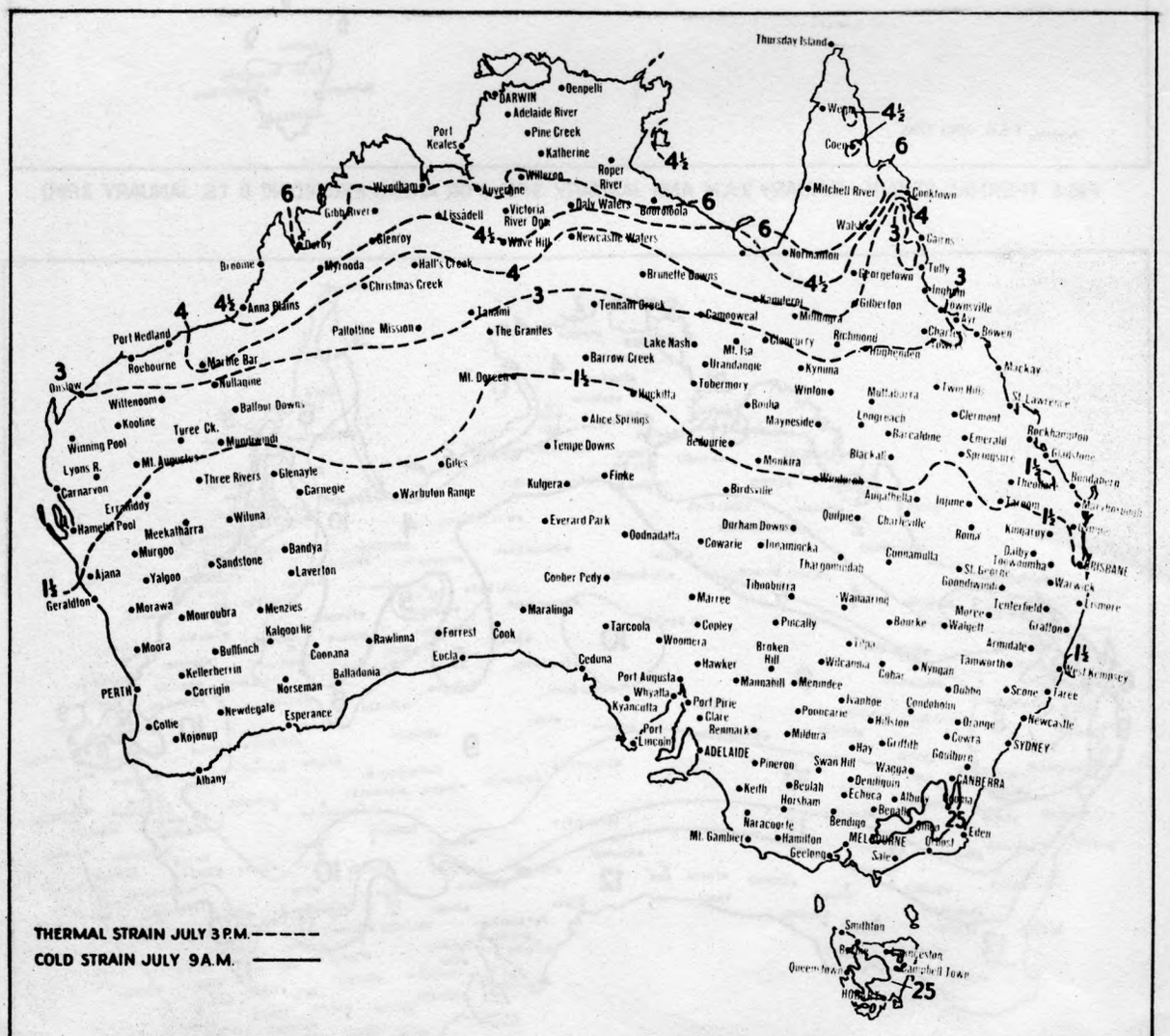


FIG 7. THERMAL STRAIN - JULY 9 A.M. AND JULY 3 P.M.